

ADVANCED MATERIALS

Supporting Information

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Chiroptical Switching of Electrochromic Polymer Thin Films

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Supporting Information for

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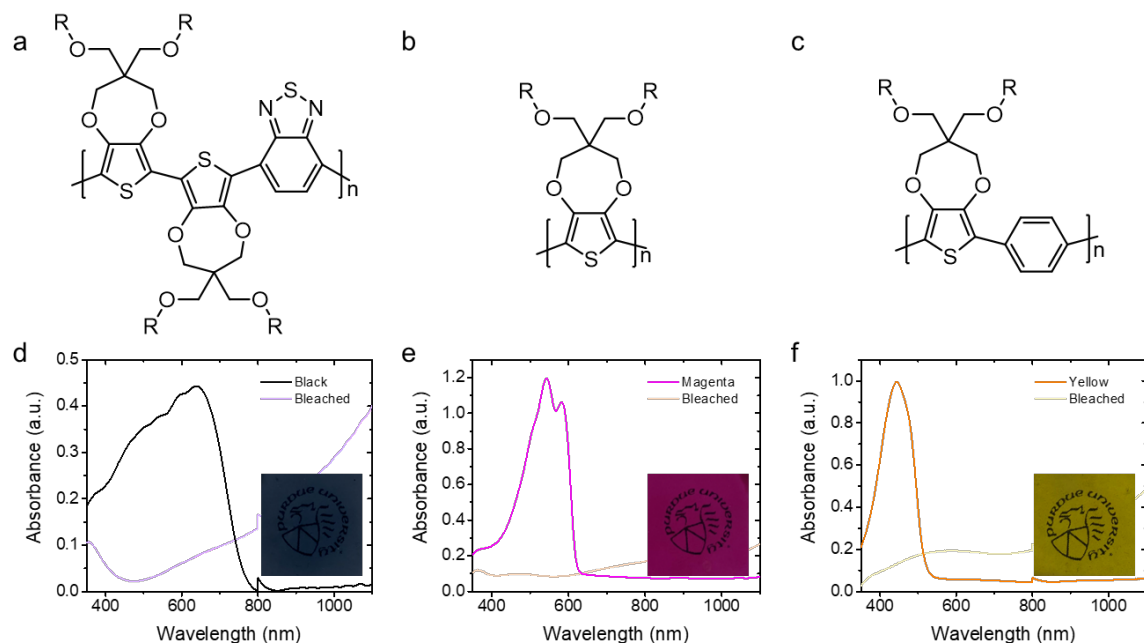


Figure S1. a–c) Molecular structures of EC polymer black (a), magenta (b), and yellow (c). R = 2-ethylhexyl. d–f, Optical absorbance spectra of pristine EC polymer films of black (d), magenta (e), and yellow (f) depending on the electrochemical bias. Inset figures show photographic images of the EC polymer films at coloration state.

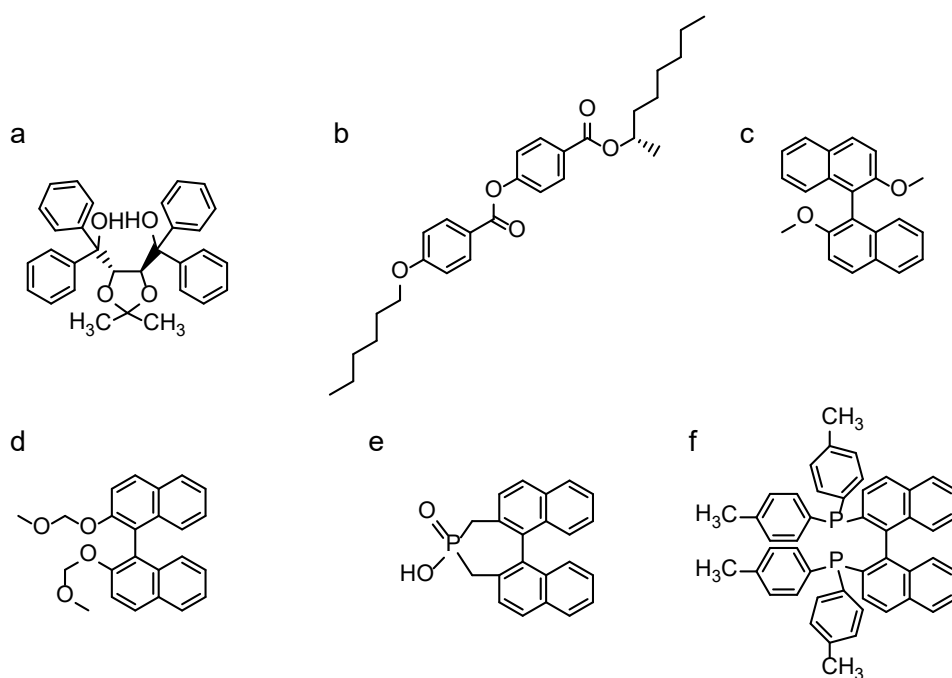


Figure S2. a–f) Molecular structures of chiral additives of (-)-4,5-Bis[hydroxy(diphenyl)methyl]-2,2-dimethyl-1,3-dioxolane; *S*-taddol (a), (*R*)-Octan-2-yl 4-((4-(hexyloxy)benzoyl)oxy)benzoate; R811 (b), (*R*)-(+)-2,2'-Dimethoxy-1,1'-binaphthyl (c), (*R*)-(+)-2,2'-Bis(methoxymethoxy)-1,1'-binaphthyl (d), (*R*)-(-)-1,1'-Binaphthyl-2,2'-diyl hydrogenphosphate (e), and (*S*)-(-)-2,2'-Bis(di-*p*-tolylphosphino)-1,1'-binaphthyl (f).

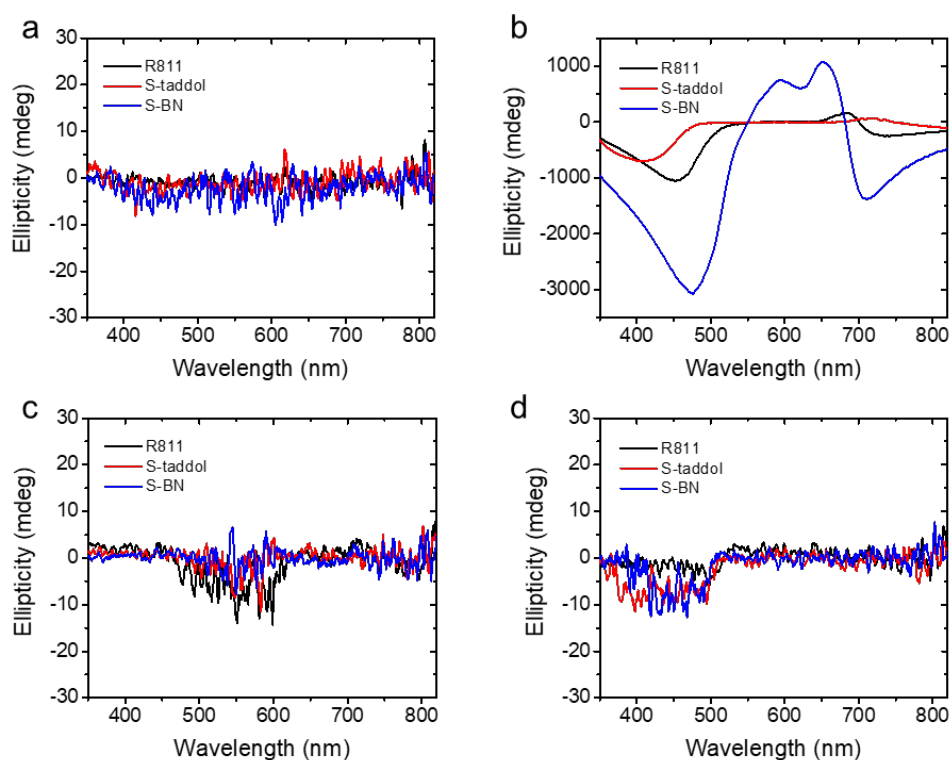


Figure S3. a–d) Ellipticity spectra of chiral templated EC polymer films (25 wt%) using ECP-Black (a), ECP-Blue (b), ECP-Magenta (c), and ECP-Yellow (d).

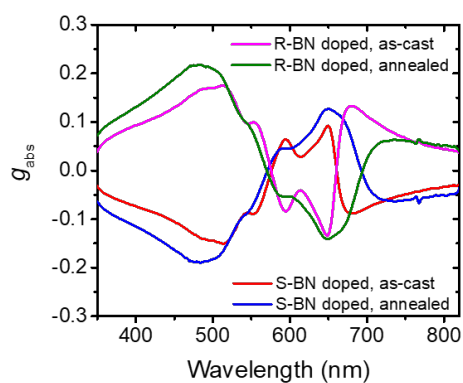


Figure S4. Calculated g_{abs} values from absorbance and ellipticity recorded in CD spectrometer.

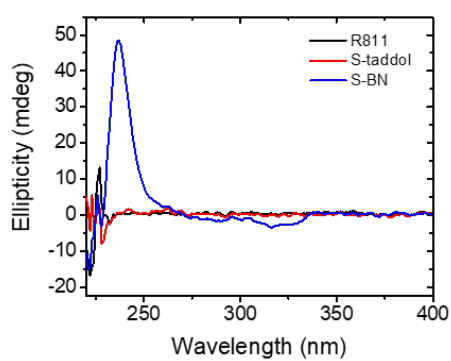


Figure S5. Ellipticity spectra of chiral additives solutions (0.05 mg mL^{-1}) in chloroform.

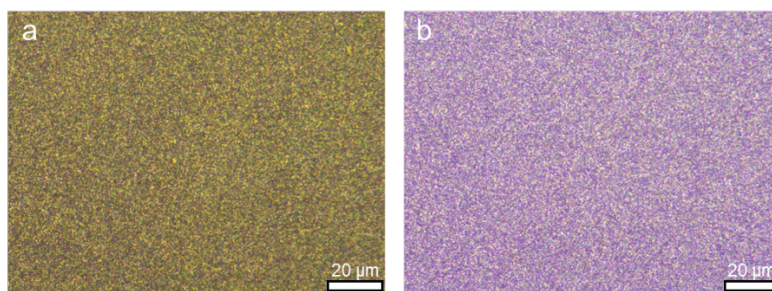


Figure S6. a, b) Polarizing optical microscopy images of S-BN templated ECP-Blue before (**a**) and after (**b**) thermal treatment.

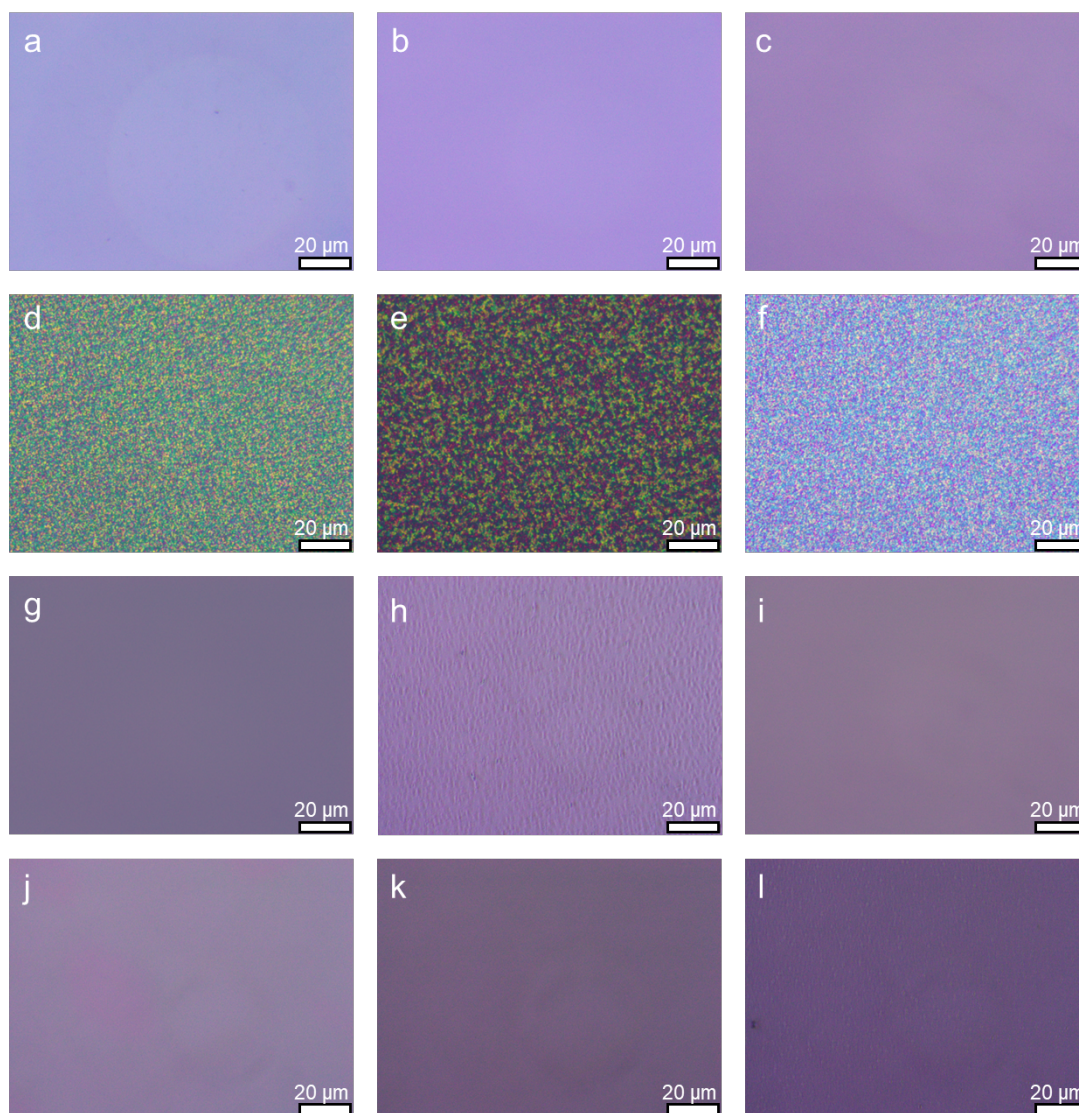


Figure S7. **a–c)** Polarizing optical microscopy images of ECP-Black blended with R811 (**a**), *S*-taddol (**b**), and *S*-BN (**c**) with 25 wt% concentration after thermal treatment. **d–f)** Polarizing optical microscopy images of ECP-Blue blended with R811 (**d**), *S*-taddol (**e**), and *S*-BN (**f**) with 25 wt% concentration after thermal treatment. **g–i)** Polarizing optical microscopy images of ECP-Magenta blended with R811 (**g**), *S*-taddol (**h**), and *S*-BN (**i**) with 25 wt% concentration after thermal treatment. **j–l)** Polarizing optical microscopy images of ECP-Yellow blended with R811 (**j**), *S*-taddol (**k**), and *S*-BN (**l**) with 25 wt% concentration after thermal treatment.

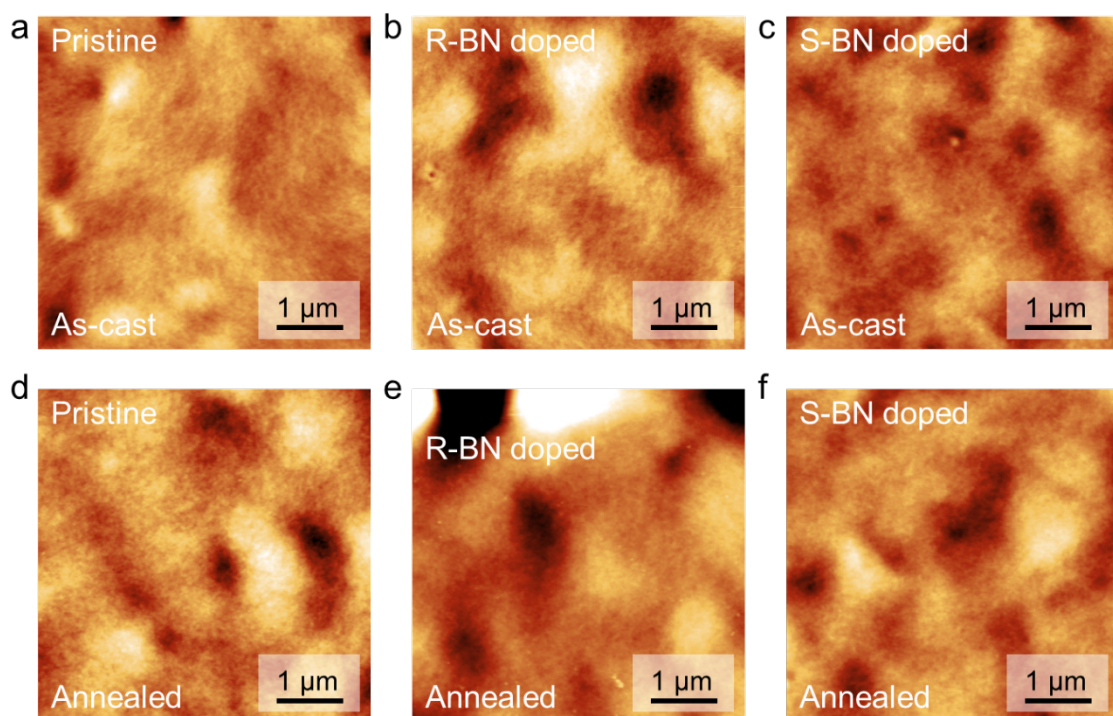


Figure S8. **a–c)** AFM measurement results of pristine **(a)**, *R*-BN templated **(b)**, and *S*-BN templated **(c)** ECP-Blue films before thermal annealing. **d–f)** AFM measurement results of pristine **(d)**, *R*-BN templated **(e)**, and *S*-BN templated **(f)** ECP-Blue films after thermal annealing.

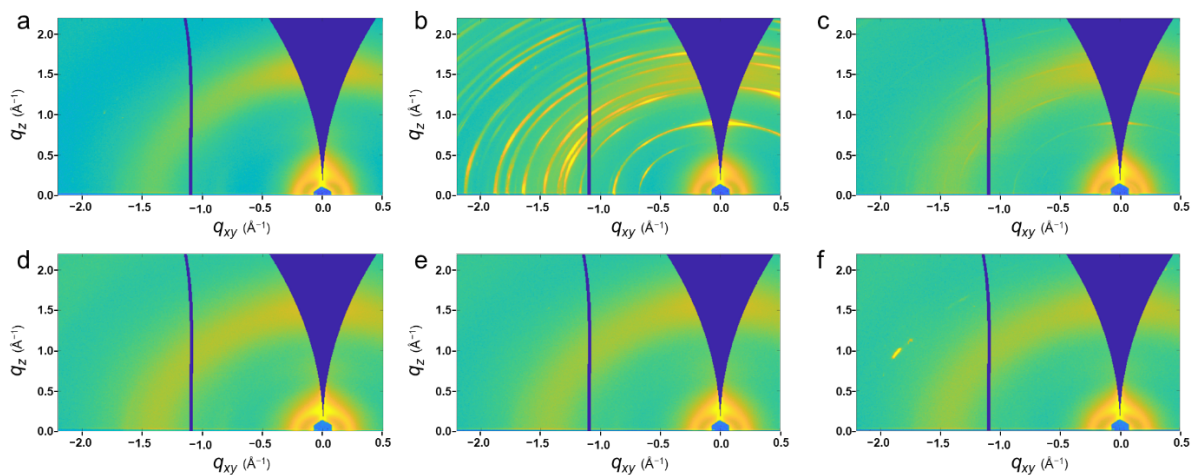


Figure S9. **a–c)** 2D GIXD results of pristine **(a)**, *R*-BN templated **(b)**, and *S*-BN templated **(c)** ECP-Blue films before thermal annealing. **d–f)** 2D GIXD results of pristine **(d)**, *R*-BN templated **(e)**, and *S*-BN templated **(f)** ECP-Blue films after thermal annealing.

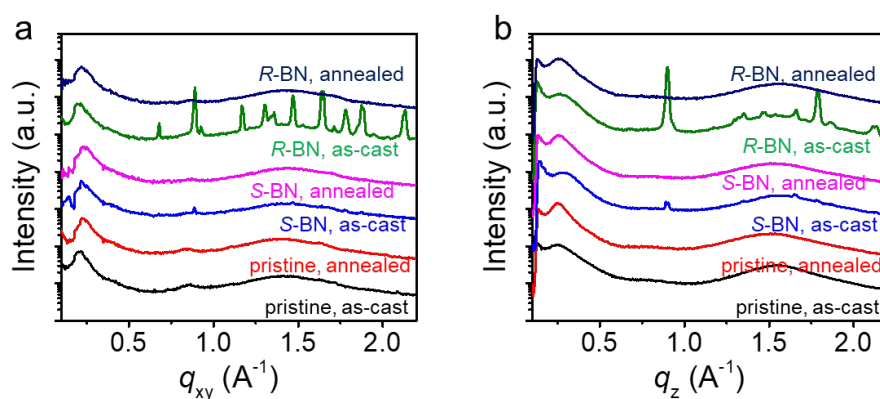


Figure S10. a, b) 1D GIXD profiles of in-plane (a) and out-of-plane (b) diffraction patterns of ECP-Blue films before and after thermal annealing.

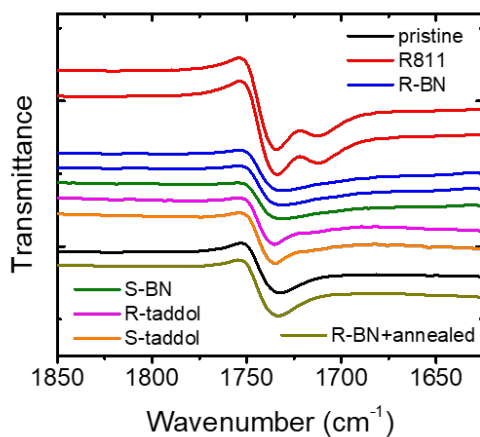


Figure S11. FTIR spectra of pristine and chiral templated ECP-Blue films before and after thermal annealing.

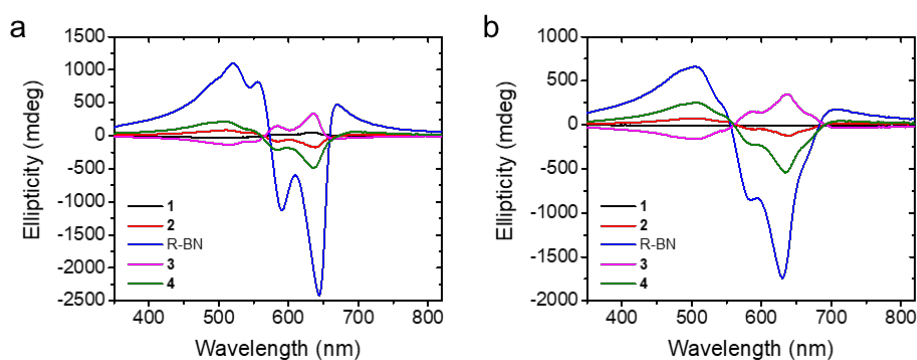


Figure S12. a, b) Ellipticity spectra of chiral templated ECP-Blue before (a) and after (b) thermal treatment with chiral BN derivatives. **1:** (*R*)-(-)-1,1'-Binaphthyl-2,2'-diyl hydrogenphosphate, **2:** (*R*)-(+)-2,2'-Bis(methoxymethoxy)-1,1'-binaphthyl. **3:** (*S*)-(-)-2,2'-Bis(di-*p*-tolylphosphino)-1,1'-binaphthyl, **4:** (*R*)-(+)-2,2'-Dimethoxy-1,1'-binaphthyl.

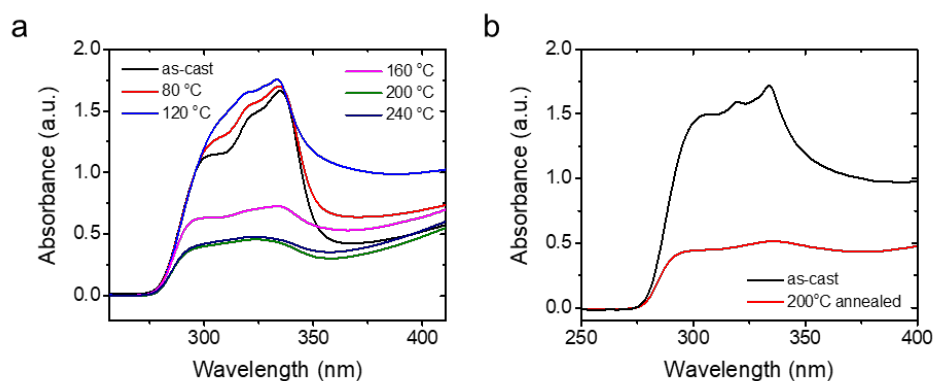


Figure S13. a) Optical absorbance spectra of *S*-BN templated ECP-Blue films depending on the annealing temperatures. b) Optical absorbance spectra of *S*-BN templated ECP-Blue films aged for 2 months before and after thermal annealing.

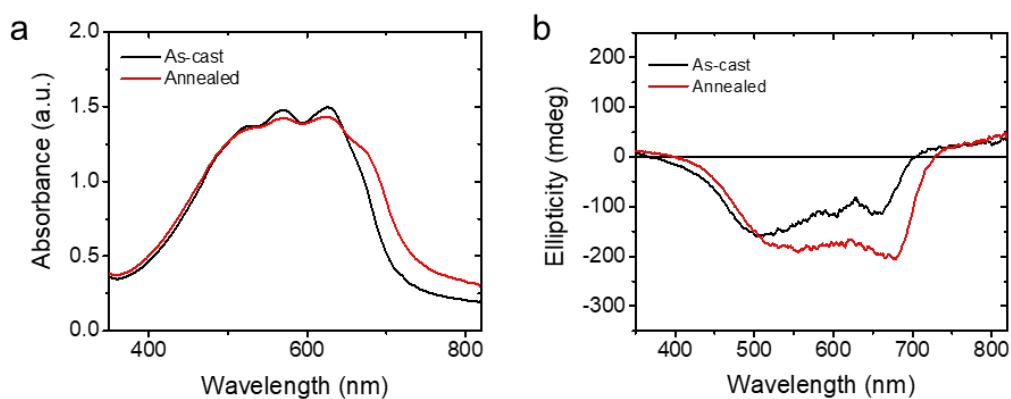


Figure S14. a) Optical absorbance spectra of native ECP-Blue films. b) Ellipticity spectra of native ECP-Blue films.

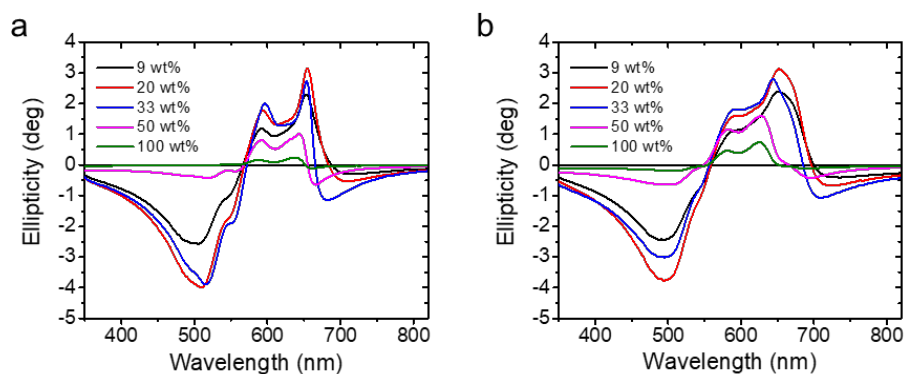


Figure S15. a, b) Ellipticity spectra of *S*-BN templated ECP-Blue before (a) and after (b) thermal treatment.

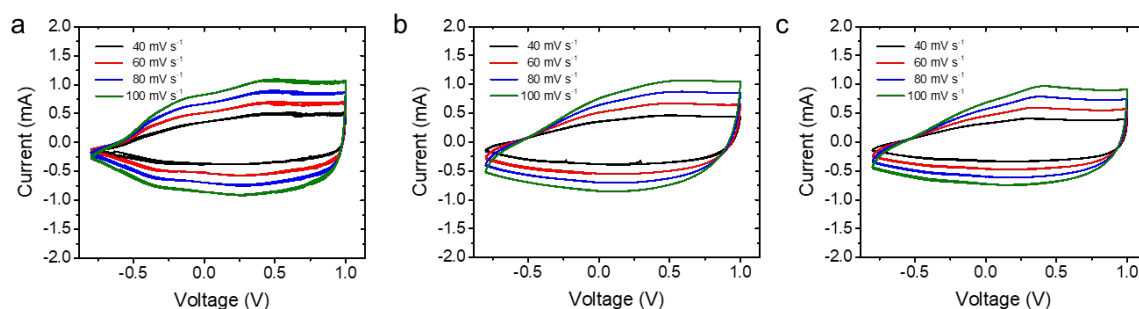


Figure S16. a–c) Cyclic voltammetry results of achiral (a), *S*-BN templated (b), and *R*-BN templated (c) ECP-Blue EC devices after thermal annealing.

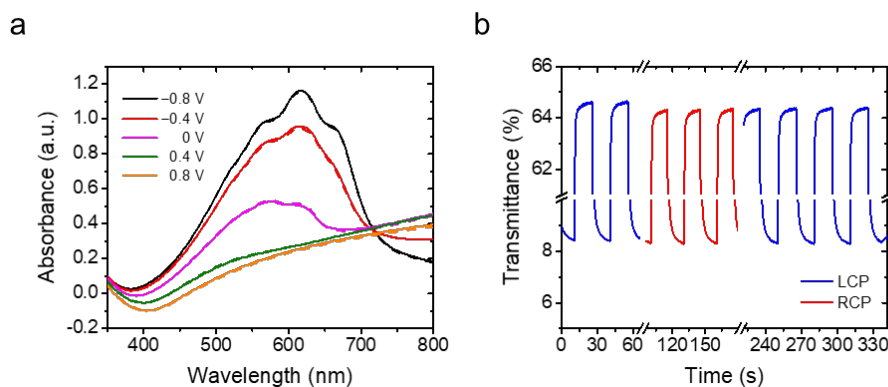


Figure S17. a) Optical absorbance of pristine (achiral) ECP-Blue EC devices after thermal annealing upon the left-handed circularly polarized light (solid line) and right-handed one (dotted line). b) Optical transmittance of pristine ECP-Blue EC devices upon the left-handed circularly polarized light (blue) and right-handed one (red) after thermal annealing.

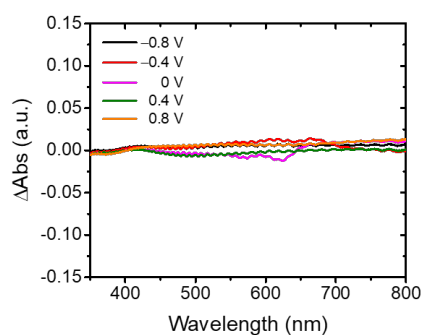


Figure S18. Differential optical absorbance of pristine (achiral) ECP-Blue EC devices after thermal annealing.

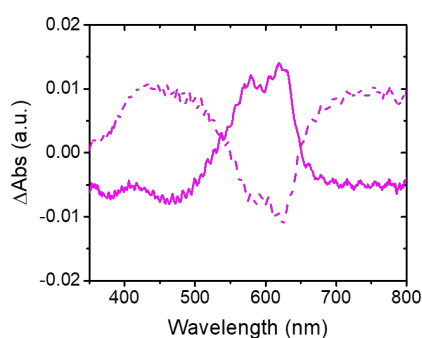


Figure S19. Differential optical absorbance of *S*-BN templated ECP-Blue EC devices (solid line) and *R*-BN templated one (dotted line) after thermal annealing at 0 V.

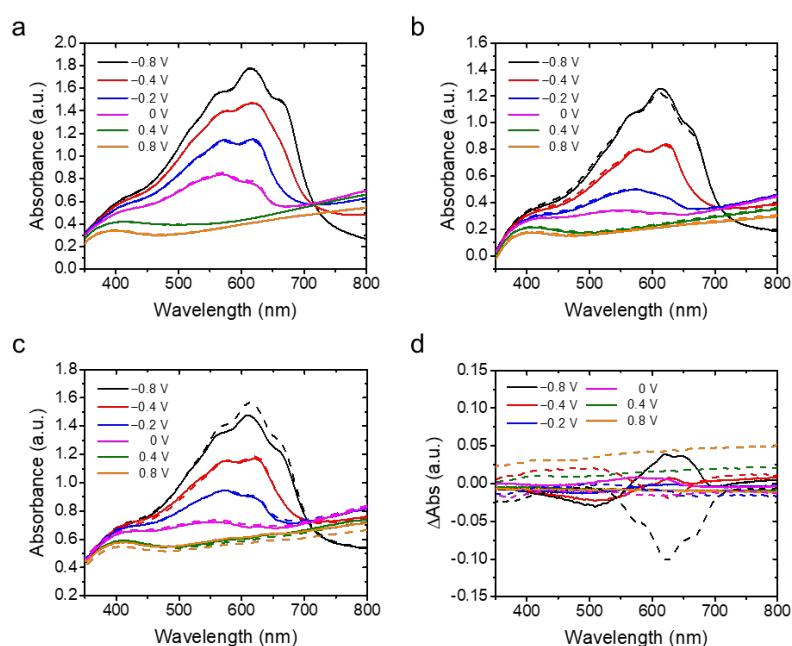


Figure S20. a–c) Optical absorbance of achiral (a), *S*-BN templated (b), and *R*-BN templated (c) ECP-Blue EC devices before thermal annealing upon the left-handed circularly polarized light (solid line) and right-handed one (dotted line). **d)** Differential optical absorbance of *S*-BN templated ECP-blue EC devices (solid line) and *R*-BN templated one (dotted line) before thermal annealing.

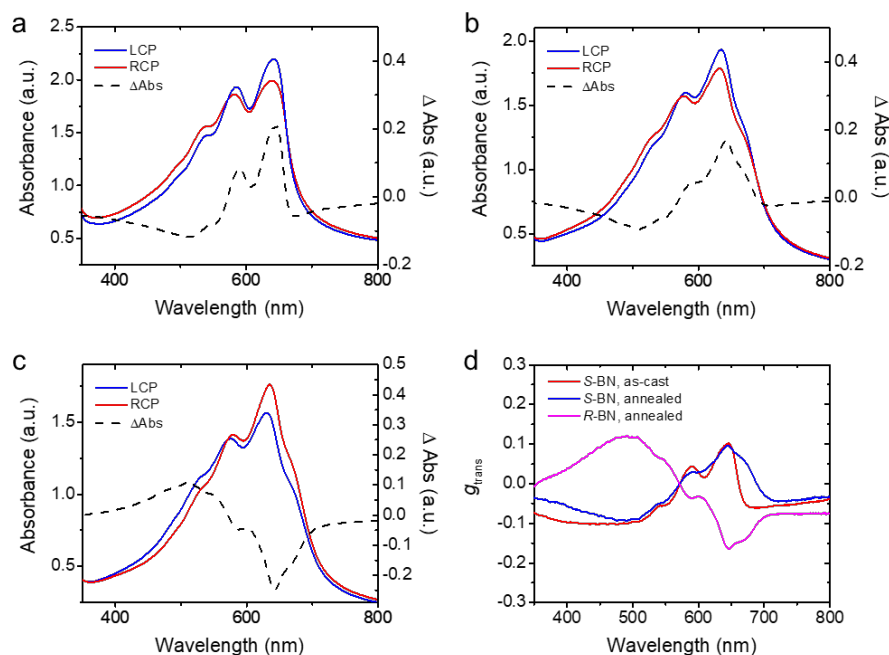


Figure S21. **a)** Optical absorbance of *S*-BN templated ECP-Blue EC devices without thermal annealing before a redox reaction. **b, c)** Differential optical absorbance of *S*-BN templated (**b**) and *R*-BN templated (**c**) ECP-Blue EC devices with thermal annealing before a redox reaction. **d)** Defined g_{trans} values from optical absorbances shown in (**a–c**).

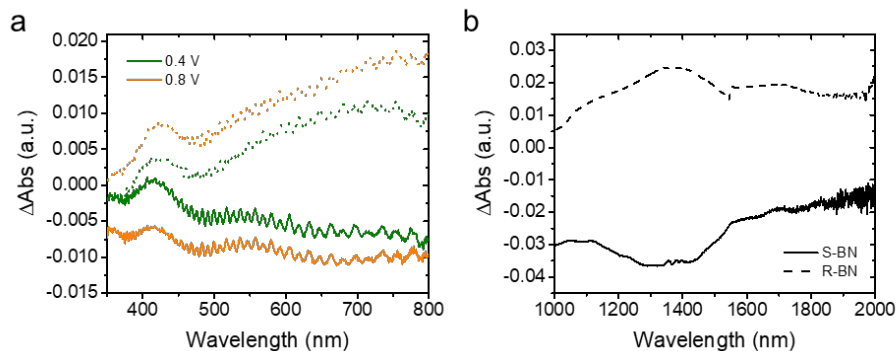


Figure S22. **a)** Differential optical absorbance of *S*-BN templated ECP-blue EC devices (solid line) and *R*-BN templated one (dotted line) after thermal annealing at 0.4 V and 0.8 V for oxidizing polymers. **b)** Differential optical absorbance of *S*-BN templated ECP-blue EC devices (solid line) and *R*-BN templated one (dotted line) after thermal annealing at 0.8 V at SWIR-region.

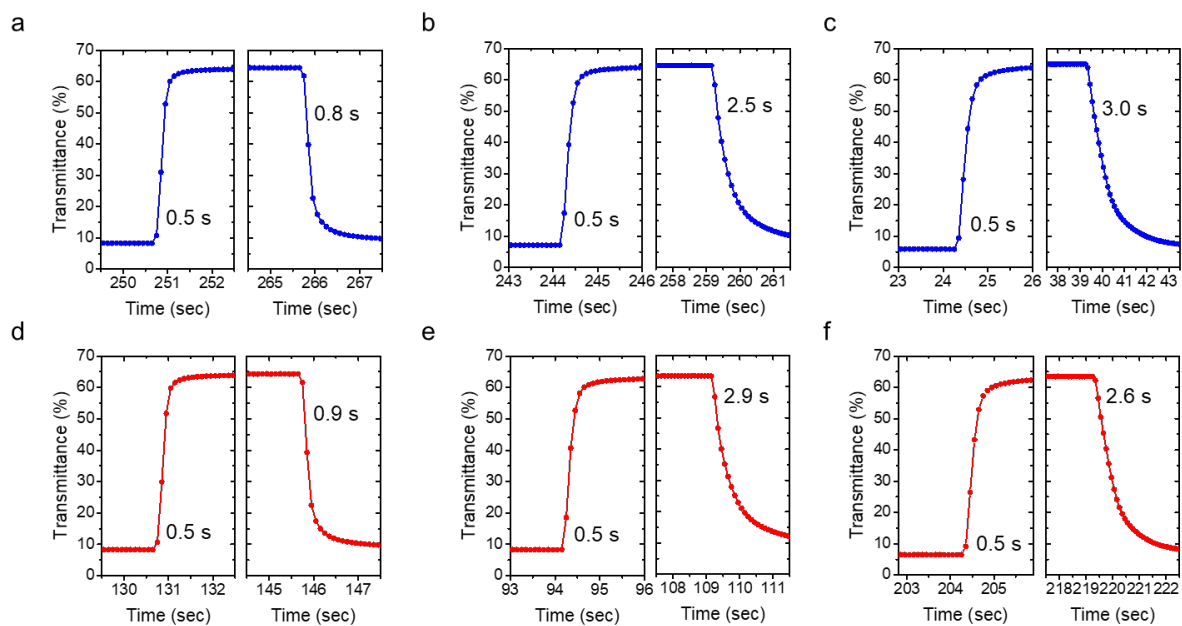


Figure S23. **a–c)** Estimated coloration and bleached switching time at dynamic optical transmittance results of pristine **(a)**, *S*-BN templated **(b)**, and *R*-BN templated **(c)** ECP-Blue EC devices upon the left-handed circularly polarized light after thermal annealing. **d–f)** Estimated coloration and bleached switching time at dynamic optical transmittance results of pristine **(d)**, *S*-BN templated **(e)**, and *R*-BN templated **(f)** ECP-Blue EC devices upon the right-handed circularly polarized light after thermal annealing. The switching rates were estimated with a 95% complete switching time both coloration and bleaching.

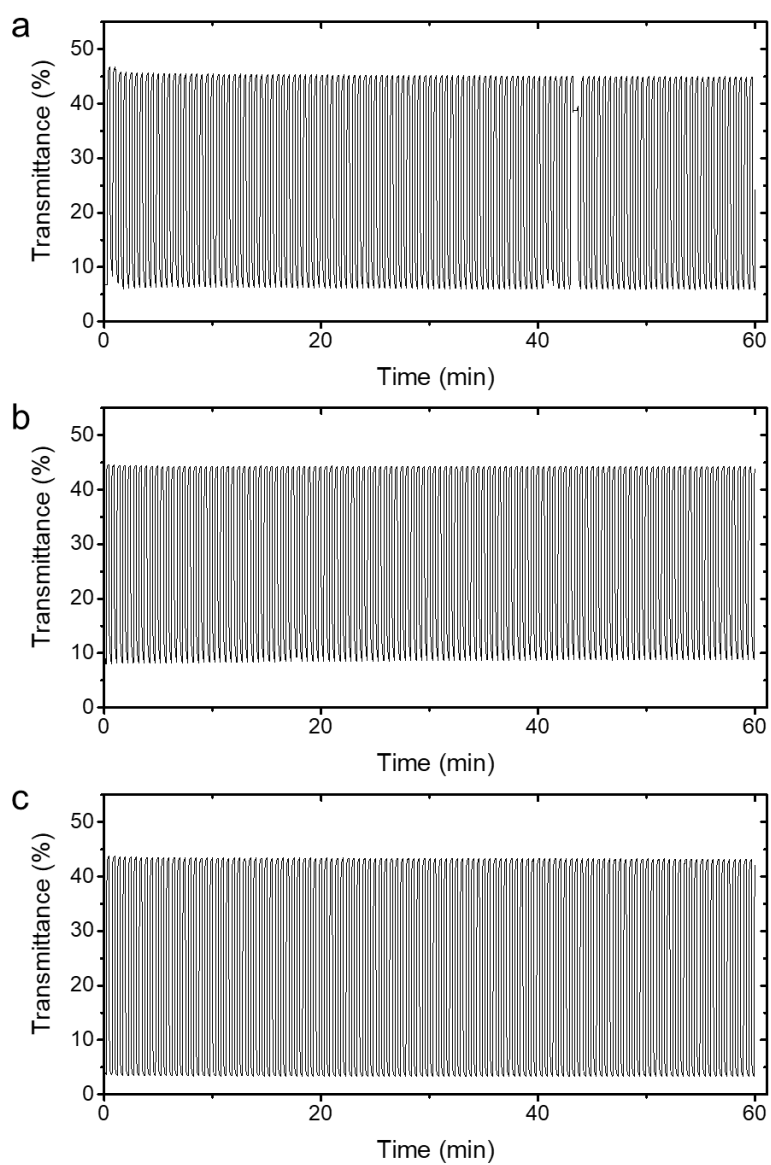


Figure S24. a–c) Transmittance changes of pristine (a), *S*-BN templated (b), and *R*-BN templated (c) ECP-Blue EC devices in EC switching for 1 hr.

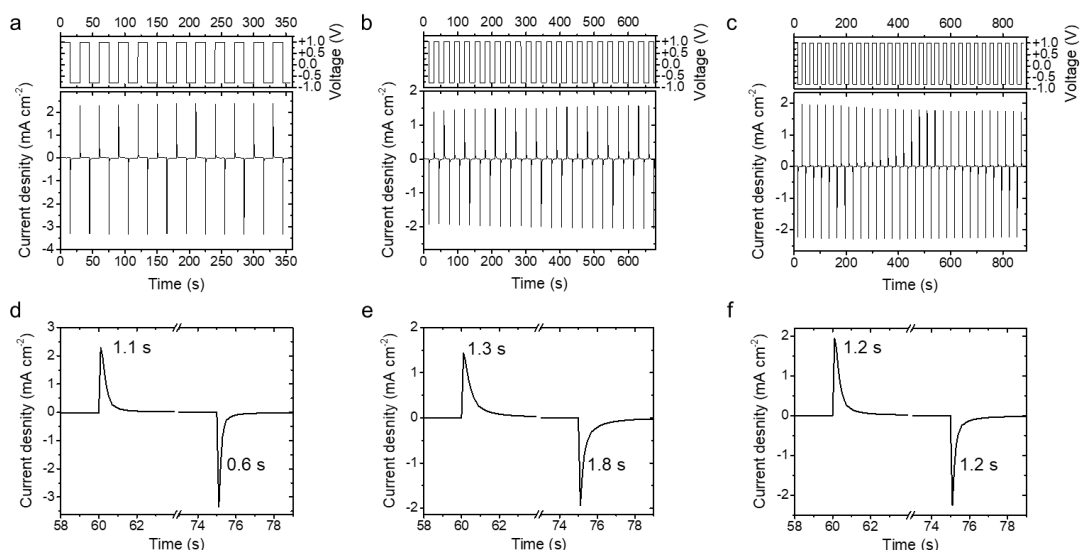


Figure S25. **a–c)** Current density profile in CA response of pristine **(a)**, *S*-BN templated **(b)**, and *R*-BN templated **(c)** ECP-Blue EC devices after thermal annealing. **d–f)** Magnified current density profile in CA response of pristine **(d)**, *S*-BN templated **(e)**, and *R*-BN templated **(f)** ECP-Blue EC devices after thermal annealing. The switching rates were estimated with a 95% complete switching time both coloration and bleaching.

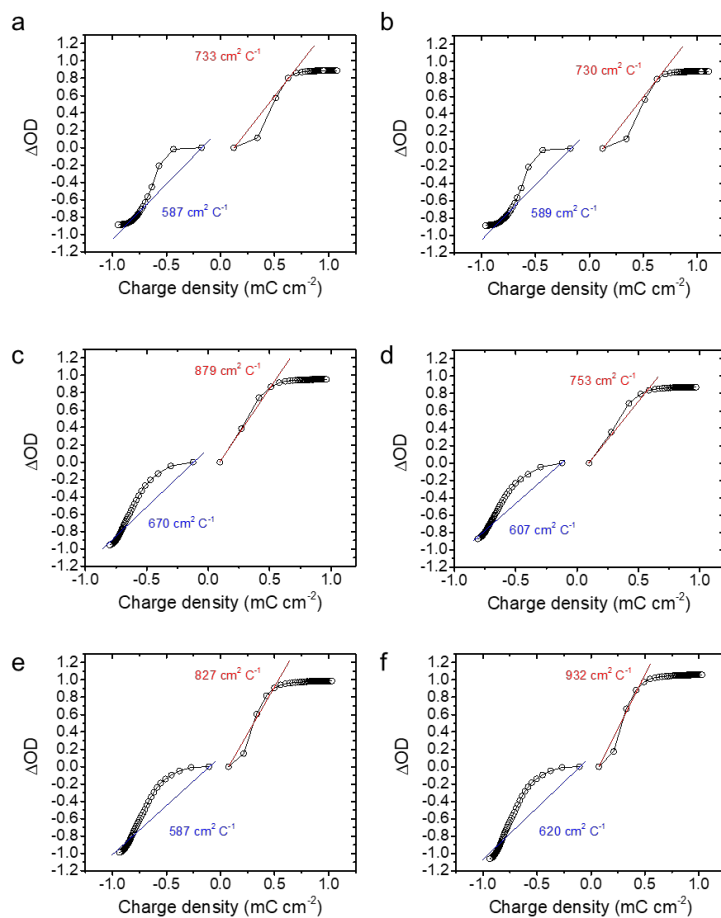


Figure S26. **a, b)** Bleaching and coloration efficiency of pristine (achiral) ECP-Blue films upon the left-handed circularly polarized light **(a)** and right-handed one **(b)** after thermal annealing. **c, d)** Bleaching and coloration efficiency of *S*-BN templated ECP-Blue films upon the left-handed circularly polarized light **(c)** and right-handed one **(d)** after thermal annealing. **e, f)** Bleaching and coloration efficiency of *R*-BN templated ECP-Blue films upon the left-handed circularly polarized light **(e)** and right-handed one **(f)** after thermal annealing.

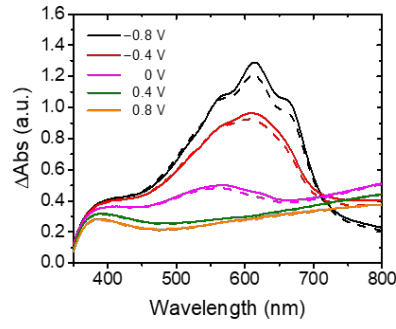


Figure S27. Optical absorbance of *S*-BN templated ECP-Blue EC devices after thermal annealing recorded through the left-handed circularly polarized light filter (solid line) and right-handed one (dotted line).

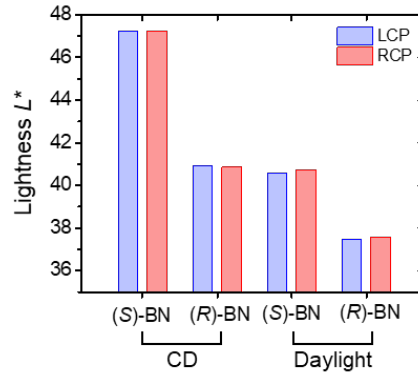


Figure S28. Lightness (L^*) of *S*-BN templated and *R*-BN templated ECP-Blue EC devices after thermal annealing.

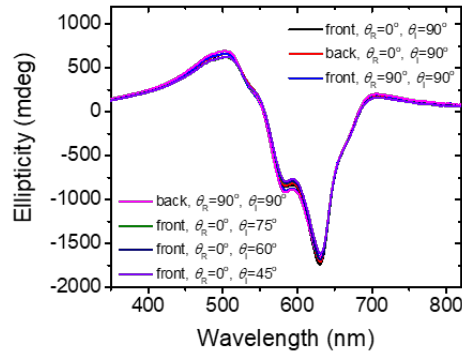


Figure S29. Ellipticity spectra of *R*-BN templated ECP-Blue films depending on the circularly polarized light exposure conditions, considering the azimuthal sample rotation, sample flipping, and incidence angle modulation. θ_R is rotation angle of the sample and θ_I is incidence angle of the beam.

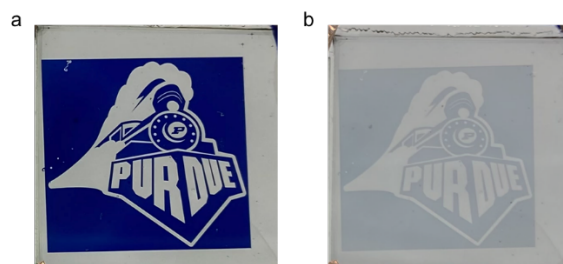


Figure S30. **a, b)** Photographic images of patterned *S*-BN templated EC display at coloration (**a**) and bleached (**b**) states.

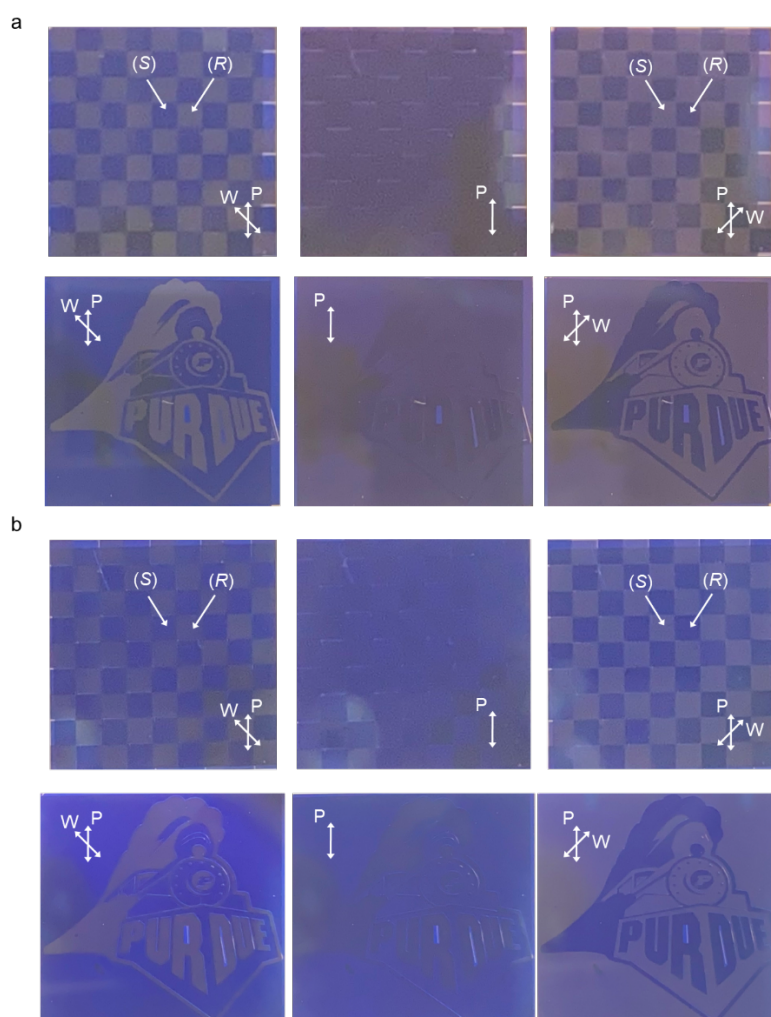


Figure S31. **a, b)** Photographic images of chiral EC displays by patterning differential chiral templated EC polymer to “Train”-shaped segment image. Different chiral filter was placed between chiral EC display and a picture capturing digital camera. D65, artificial daylight, (**a**) and TL84, store light, (**b**) was used as artificial daylight sources for ambient condition demonstration.



Figure S32. Photographic images of chiral EC displays by patterning differential chiral templated EC polymer to “Train”-shaped segment image through chiral filter which have different polarization axis to display.

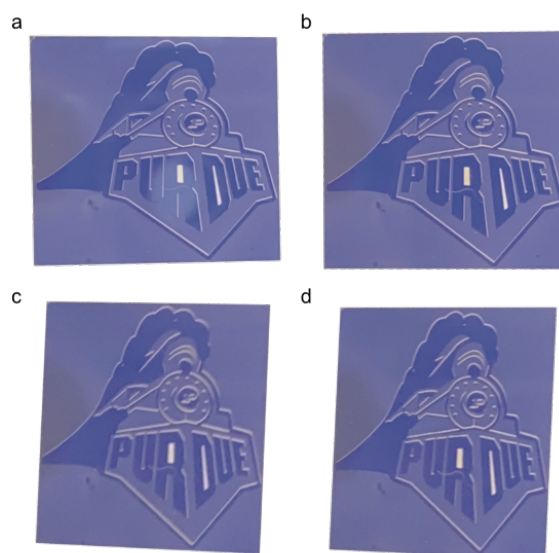


Figure S33. Photographic images of chiral EC displays by patterning differential chiral templated EC polymer to “Train”-shaped segment image through chiral filter at different viewing-angle of 90° (a), 75° (b), 60° (c), and 50° (d).

Table S1. Crystallographic parameters from GIXD results for the ECP-Blue films.

peak direction	Peak	additive	annealing	q value	stacking distance (Å)
In-plane	(100)	Pristine	As-cast	0.259	24.19
			annealed	0.255	24.55
		S	As-cast	0.292	21.32
			annealed	0.260	24.20
		R	As-cast	0.282	22.31
			annealed	0.260	24.20
		Pristine	As-cast	1.631	3.85
			annealed	1.635	3.84
		S	As-cast	1.674	3.75
			annealed	1.695	3.71
Out-of-plane	(010)	R	As-cast	1.683	3.73
			annealed	1.704	3.69

Movie S1. Recorded movie of chiral EC displays by patterning differential chiral templated EC polymer to “Train”-shaped segment image. Chiral filter was placed between chiral EC display and a video recording digital camera. Type A incandescent, home light was used as artificial daylight sources for ambient condition demonstration. The retarder was rotated to see transmitted, polarized light through circularly polarized and linearly polarized light filter depending on the subtitle. “LCP” indicates that we (i.e., recording digital camera) can see only left-handed circularly polarized light through filter with -45° retarder rotated. “LP” and “RCP” indicates that we can see only linearly polarized light and right-handed circularly polarized light through filter with 0 and $+45^\circ$ retarder rotated, respectively.